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U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

'64 13

PROJECT GNOME
DESIGN, TESTING, AND FIELD PUMPING OF GROUT MIXTURES

MISCELLANEOUS PAPER NO. 6-514

July 1962

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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NUCLEAR EXPLOSIONS—PEACEFUL APPLICATIONS

DESIGN, TESTING, AND FIELD PUMPING OF GROUT MIXTURES, FINAL REPORT

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Ralph A. Bendinelli

U. S. Army Corps of Engineers
Waterways Experiment Station
Vicksburg, Mississippi

March, 1962

ABSTRACT

In Project GNOME, a 5-KT nuclear device was detonated at the end of a 335-m-long buttonhooked and self-sealing tunnel excavated at a 366-m depth in a salt formation in New Mexico. The primary purposes of the project were to explore (a) the feasibility of recovering, and converting for electric-power generation, energy from heat reservoirs formed underground by nuclear explosions, and (b) the practicability of recovering radioisotopes for peaceful uses. The U. S. Army Engineer Waterways Experiment Station furnished drilling consultant services, and performed core testing and grouting operations in connection with Project GNOME. The latter included (a) performing physical tests and petrographic examinations on salt cores from the project site; (b) designing grout mixtures, to match physical properties of the salt, for use in grouting instruments in place and in connection with installing underground structural appurtenances; and (c) drilling and grouting at the site to embed scientific instruments and in connection with structural work within the tunnel.

PREFACE

The laboratory work performed by the U. S. Army Engineer Waterways Experiment Station (WES) in connection with Project GNOME was accomplished during the years 1959-1961. The field work was conducted during October-December 1961. The work was performed for the U. S. Atomic Energy Commission under the direction and coordination of the University of California Lawrence Radiation Laboratory. This report covers only the WES laboratory studies, drilling consultant services, and field grouting phases of the project. Other phases will be reported by the responsible participating agencies.

It is desired to acknowledge the excellent cooperation, logistic support, and assistance furnished WES by the organizations and personnel participating in the Project GNOME tests. Among these organizations were: U. S. Atomic Energy Commission, University of California Lawrence Radiation Laboratory, Holmes and Narver, Inc., Sandia Corporation, Stanford Research Institute, and Reynolds Electrical and Engineering Co., Inc.

The WES phase of the overall project was performed under the supervision of Messrs. J. M. Polatty, Arthur L. Mathews, William O. Tynes, Rembert L. Curry, Ernest E. McCoy, and Ralph A. Bendinelli, and Mrs. Katharine Mather. This report was prepared by Messrs. Polatty and Bendinelli.

Col. Edmund H. Lang, CE, and Col. Alex G. Sutton, Jr., CE, were Directors, Mr. J. B. Tiffany, Technical Director, Mr. W. J. Turnbull, Chief of the Soils Division, and Mr. T. B. Kennedy, Chief of the Concrete Division of the WES during the course of the Project GNOME tests and the preparation and publication of this report.

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PROJECT GNOME

DESIGN, TESTING, AND FIELD PUMPING OF GROUT MIXTURES

CHAPTER 1
INTRODUCTION

1.1 OBJECTIVES

In Project GNOME, a part of the U. S. Atomic Energy Commission's PLOWSHARE Program, a 5-KT nuclear device was detonated at the end of a 335-m-long buttonhooked and self-sealing tunnel excavated at a 366-m depth in a salt formation located approximately 51 km southeast of Carlsbad, New Mexico (see fig. 1). The objectives of Project GNOME were to:

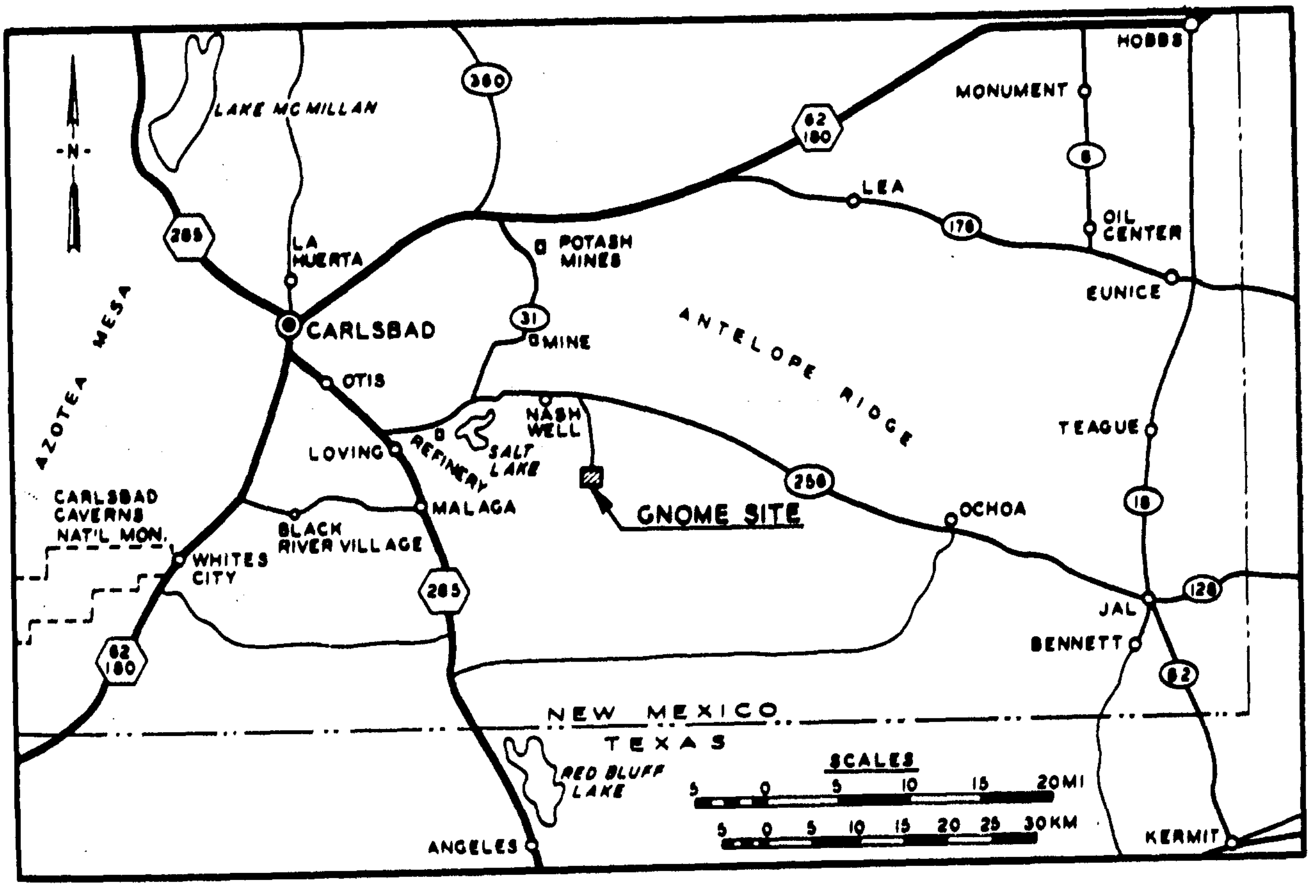


Fig. 1. Location of Project GNOME site

a. Determine the feasibility of recovering, and converting for the generation of electric power, energy from heat reservoirs formed underground as the result of nuclear explosions.

b. Distinguish the characteristics of underground nuclear explosives

detonated in a salt formation from those detonated in other types of formations.

c. Study the practicability of recovering useful radioisotopes for peaceful applications.

d. Develop improved nuclear explosive devices for peaceful purposes only.

e. Obtain neutron measurements which will generally increase the knowledge thereof for use in future nuclear programs.

1.2 BACKGROUND

Prior to the Project GNOME tests, the U. S. Army Engineer Waterways Experiment Station (WES) was requested to develop a special grout mixture that would, when hardened, match the in-situ physical characteristics of selected salt core specimens obtained from the test site. In addition, the grout mixture was to be pumpable, shrinkage-resistant, and have adequate bond-to-salt strength. WES had successfully developed a similar grout mixture for the Project COWBOY tests conducted in the Winn Salt Dome located near Winnfield, Louisiana.

A laboratory investigation indicated that such a grout could be developed possessing the desired physical properties. This grout was to be used for embedding scientific instruments in holes drilled from within the tunnel in the salt dome and from the surface. WES was also requested to develop a variety of grout mixtures with various characteristics for use in structural work and for other miscellaneous purposes.

For Project COWBOY, WES had drilled vertical, horizontal, and sloping holes of various lengths and diameters in the salt, with rigid tolerance requirements in regard to diameter, length, direction, and location of the termini of the holes. Considerable modification of commercially available drilling equipment and the development and fabrication of new equipment by WES were necessary to obtain the capabilities required to accomplish the varied and extensive drilling. Since the drilling requirements for GNOME were to be comparable to those for COWBOY, WES was requested to provide a drilling consultant for the GNOME drilling to be performed within the tunnel and to furnish the modified or newly developed equipment used for COWBOY for accomplishing this drilling.

1.3 SCOPE OF WES PARTICIPATION IN PROJECT GNOME

The Concrete and Soils Divisions of WES were responsible for and furnished the following laboratory and field support for the project:

a. Performed physical tests on salt cores obtained from an exploratory hole and a recovery hole drilled at the site; cores and test results are described in Appendix A.

b. Developed in the laboratory (1) a grout mixture matching the in-situ physical characteristics of the salt, (2) a mixture having high compressive strength and shear resistance for use in underground structural work, and (3) a grout mixture for stemming postshot recovery holes.

c. Provided a drilling consultant at the jobsite in connection with the drilling of line-of-sight and instrument holes in the tunnel area.

d. Pumped the laboratory-developed grout mixtures at the site, including pumping grout into drilled holes for the purpose of embedding scientific instruments placed therein and for stemming postshot recovery holes. Seven instrument holes and two recovery holes, ranging from 12.7 to 30.5 cm in diameter and from 183 to 366 m deep, were grouted from the surface. In the tunnel a total of 25 horizontal and vertical instrument holes ranging from 7.62 to 30.48 cm in diameter and from a few to 41.15 m in length were grouted. WES also proportioned grout mixtures on the job for special uses as follows: (1) Grouted in place annulus areas of sections of a neutron pipe having outside diameters ranging from 55.88 to 71.12 cm; the neutron pipe passed through two horizontal holes, 91.44 cm in diameter and 9.14 and 24.38 m in length, forming the annuli which were grouted. (2) In addition, grouting was conducted for: a concrete-block plug, a steel bulkhead, two blast-door frames, a plug for the bottom of a 365.76-m-deep, 30.48-cm-diameter cable hole, a series of cable trenches and cable conduits, and for forming a grout collar for a neutron pipe gate.

Overall layout of the underground instrument holes, neutron pipe holes, and the configuration of the tunnel are shown in fig. 2.

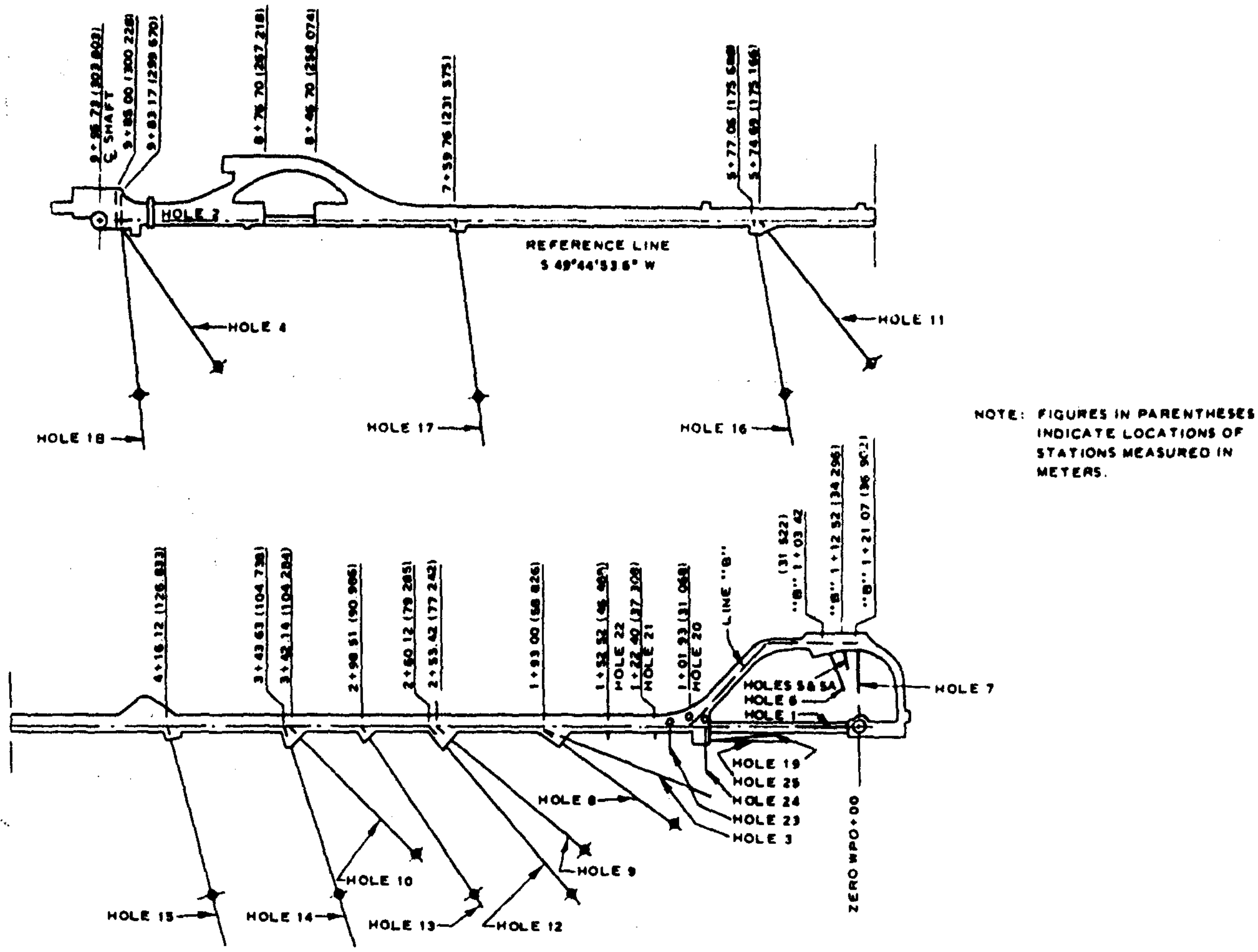


Fig. 2. GNOME tunnel

CHAPTER 2

GROUT MIXTURES

2.1 DESIGN CRITERIA

A grout mixture was required that would match as nearly as possible certain physical properties of the salt formation in which scientific instruments were to be embedded in drilled holes by means of grouting. Design requirements were based on the results of physical tests performed on salt core specimens 1 through 4 which were obtained from recovery hole 1 (see Appendix A). The physical properties determined on these specimens were selected for design criteria rather than the physical properties determined on the specimens obtained from exploratory hole 1 because the specimens from recovery hole 1 were more representative of the area of the salt formation in which the majority of the embedded instrumentation was to be placed. The principal physical properties to be matched are given in table A1 of Appendix A, an ultrasonic pulse velocity of approximately 3979 m per sec and a density of 2130 kg per cu m.

The second requirement was for a high-compressive-strength and shear-resistant grout for use in grouting in connection with the installation of structural appurtenances within the tunnel.

A third requirement was to develop a drillable grout for stemming postshot recovery holes that extended from the ground surface either into or in the immediate area of the device chamber.

The series of grout mixtures designed in the laboratory to meet these requirements are described in the following paragraphs.

2.2 MATERIALS AND LABORATORY MIXTURES

The following materials were used in the proportioning studies for developing the various grout mixtures required for the project:

Material	Specific Gravity	Unit Weight (Solid) kg/cu m	Absorption, %
Portland cement, Type III	3.15	3143.76	---
Portland cement, Type II	3.15	3143.76	---

(Continued)

Material	Specific Gravity	Unit Weight (Solid) kg/cu m	Absorption, %
Silica sand, natural*	2.61	2604.85	0.9
Bentonite, natural swelling	2.20	2195.70	---
Salt, fine**	2.25	2245.68	---
Aluminum powder†	--	---	---

* Silica sand sieve analysis:

Sieve Opening, mm	Accumulative % Passing
4.76	99
2.38	96
1.19	90
0.59	77
0.297	45
0.149	6
0.074	5

** Fine salt was used for bringing water to saturated brine condition.

† Atomized granular; 94% passing No. 325 (sieve opening 0.044 mm) U. S. Standard Sieve.

The following three grout mixtures were proportioned in the laboratory to meet the three requirements previously described in paragraph 2.1:

Material	Proportions for a 1-Bag Batch: Solid Volume, cu m	Proportions for a 1-Bag Batch: Dry Batch Weights, kg (SSD)*
Mixture 1, Instrument Grout, Surface and Tunnel Holes		
Cement, Type II	0.0136	42.64
Salt, fine	0.0040	9.03
Sand, silica	0.0310	81.65
Water	0.0256	25.58
Aluminum powder	Negligible	(6.0 g)
Mixture 2, Underground Structural Work		
Cement, Type II	0.0136	42.64
Salt, fine	0.0030	6.80
Sand, silica	0.0209	54.43
Water	0.0214	21.32
Aluminum powder	Negligible	(4.0 g)
Mixture 3, Postshot Recovery Holes		
Cement, Type II	0.0136	42.64
Bentonite, natural swelling	0.0029	6.40
Sand, silica	0.0207	54.43
Water	0.0470	46.90
Aluminum powder	Negligible	(7.0 g)

* (SSD) = saturated, surface-dry weights.

2.3 PHYSICAL TESTS OF LABORATORY MIXTURES

Specimens of grout mixtures 1 through 3 were tested at 28 days age to determine their physical properties. Results were as follows:

Test	Mixture No.		
	1	2	3
Compressive strength, kg/sq cm	314.2	442.9	147.6
Unit weight (hardened), kg/cu m	2119.45	2180.32	1786.23
Ultrasonic pulse velocity, m/sec	3603	3755	---
Shear strength, kg/sq cm, static loading (approx)	28.8	35.1	---

2.4 MIXTURES PROPORTIONED AT PROJECT SITE

In addition to the mixtures developed in the laboratory, grout mixtures 4 through 8 were proportioned at the jobsite by WES to meet immediate job requirements. Mixture 9, a high-density grout containing **nickel** powder, was proportioned by personnel of the University of California Lawrence Radiation Laboratory and pumped by WES at the jobsite.

Material	Proportions for a 1-Bag Batch	
	Solid Volume, cu m	Dry Batch Weights, kg (SSD)
Mixture 4, LRL Hole 3, Hole from Surface*		
Cement, Type III	0.0136	42.64
Bentonite, natural swelling	0.0008	1.72
Water	0.0390	38.92
Aluminum powder	Negligible	(10.0 g)
Mixture 5, Structural Appurtenances in Tunnel		
Cement, Type III	0.0136	42.64
Salt, fine	0.0030	6.80
Water	0.0246	24.54
Aluminum powder	Negligible	(3.0 g)
Mixture 6, Surface and Tunnel Instrument Holes**		
Cement, Type II	0.0136	42.64
Salt, fine	0.0040	9.03
Water	0.0256	25.58
Aluminum powder	Negligible	(5.0 g)

(Continued)

* This mixture was essentially the same mixture used for embedding instruments in a 234.70-m-deep, 30.5-cm-diameter hole drilled from the surface in connection with a nonnuclear shot conducted for Project Pre-Gnome.

** This mixture requested by users for various types of instrumentation.

Material	Proportions for a 1-Bag Batch	
	Solid Volume, cu m	Dry Batch Weights, kg (SSD)
Mixture 7, LRL Hole 1, Grout Plug†		
Cement, Type III	0.0136	42.64
Sand, silica	0.0209	54.43
Salt, fine	0.0038	8.44
Water	0.0227	22.68
Aluminum powder	Negligible	(5.0 g)
Mixture 8, Sandia Instrument Cable Trenches Tunnel		
Cement, Type III	0.0136	42.64
Sand, silica	0.0209	54.43
Salt, fine	0.0030	6.80
Water	0.0195	14.92
Aluminum powder	Negligible	(40.0 g)
Mixture 9, LRL Nickel Powder Mixture††		
This mixture consisted of portland cement, nickel powder, silica sand, and water, proportions unknown.		

† Mixture used for key plugging the bottom 3.05 m of the LRL 1 cable hole which terminated in the ceiling of an alcove in the immediate vicinity of the device chamber.

†† LRL mixture pumped by WES and used by LRL for grouting close-in instrumentation.

CHAPTER 3
FIELD DRILLING

3.1 SCOPE

Drilling in the tunnel consisted of a number of horizontal 7.6-cm-, 12.7-cm-, 15.2-cm-, 19.4-cm-, and 30.5-cm-diameter holes of depths varying from 3.05 to 41.15 m, one 91-cm-diameter hole 24.38 m deep, and one 91-cm-diameter hole 9.14 m deep. The dimensions of all holes drilled in the tunnel are given in table 1. A WES representative was at the jobsite during the drilling to provide consultant services.

3.2 DRILLING EQUIPMENT

The following items of drilling equipment which had been used successfully for the Project COWBOY drilling were used for Project GNOME:

Quantity	Item
1	Bit, carboloy set, 3-wing type, 20.3-cm diam, pilot
2	Bits, carboloy set, 3-wing type, 12.7-cm diam, pilot
3	Guides, 20.3-cm diam
1	Flight auger, 12.7-cm diam, 8.53 m long
1	Bit, Hawthorne, 20.3-cm diam with a 12.7-cm bullnose
1	Bit, Hawthorne, 20.3-cm diam with 20.3-cm reamer
1 set	Blades, 20.3-cm diam, Hawthorne (extra)
3	Elbows with packers and salt dust collector bags
1	Bit, 30.5-cm diam, Hawthorne
1	Core barrel, 91-cm diam (special)
1 lot	Inserts, carboloy

3.3 DRILLING PROCEDURE

The drilling of the 91-cm-diameter holes was accomplished using a 91-cm-diameter by 91-cm-long core barrel with a 12.7-cm-diameter pilot extending longitudinally through the center of the barrel and 61 cm beyond the barrel cutting edge. This core barrel was designed and fabricated by WES. A 12.7-cm-diameter pilot hole was drilled in the center of each of the proposed 91-cm-diameter holes and used as a guide for the 91-cm core barrel. Drilling operations on the smaller borings (7.6- to 30.5-cm diameters) were accomplished using combinations of the equipment listed in paragraph 3.2.

CHAPTER 4

FIELD GROUTING

4.1 EQUIPMENT

The following major items of grouting equipment were used in surface and/or subsurface grouting operations:

Two Wagner steam simplex pumps, air operated.
One Gardner-Denver duplex pump, air operated.
One 0.227-cu-m-capacity, tub-type grout mixer, air operated.
Two 0.142-cu-m-capacity, tub-type grout mixers, air operated.
Two 3.823-cu-m-capacity, concrete ready-mix trucks.
Plastic grout injection hoses, 1.905 and 2.540 cm in inside diameter (ID).

4.2 TUNNEL GROUTING

To grout the vertical, sloping, and horizontal holes containing instruments and located in the tunnel, either one or two grout mixers were used with one simplex pump, the latter equipped with 1.905-cm- or 2.540-cm-ID injection hoses (fig. 3). All instrument grouting was done at a slow rate of pumping. The injection hoses were withdrawn from the holes as the grout filled the holes, or were left in the hole during grout injection, depending on the type, number, and location of the instruments in the holes. Fig. 4 shows instrument cables and grout injection hose in place in a horizontal tunnel hole immediately prior to grouting.

Fig. 3. Mixers and pump set up for tunnel grouting

Line-of-sight holes 1 and 2 through which the neutron pipe passed were grouted from the top

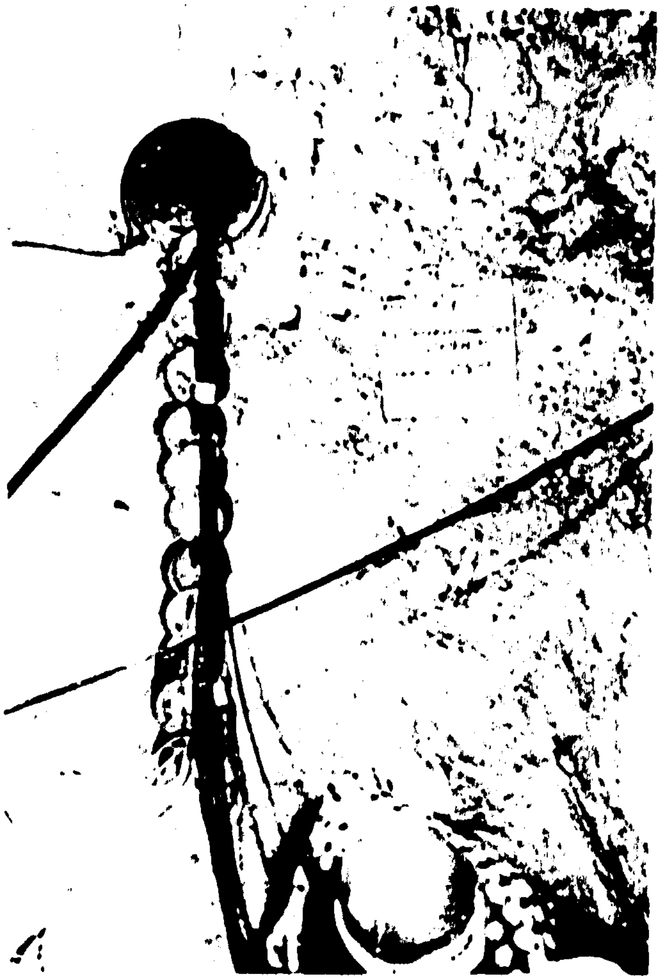


Fig. 4. Horizontal instrument hole prepared for grouting in tunnel

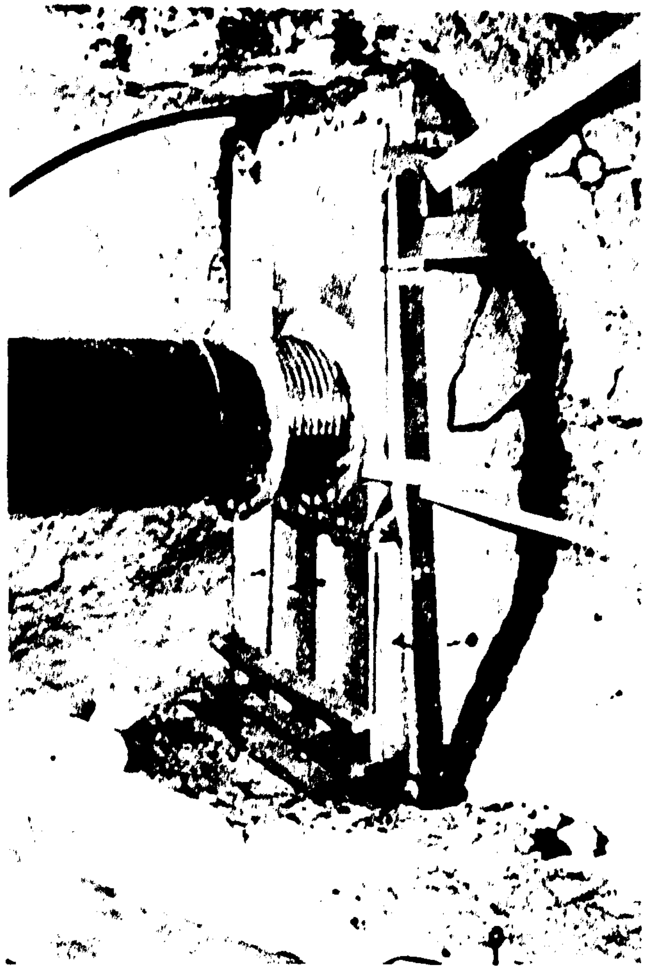


Fig. 5. Forming, grout collar for neutron pipe gate

section of the hole using 2.540-cm-ID injection hoses with tag lines attached to the hose to permit grout injection at random locations in the annulus formed between the outside of the neutron pipe and the walls of these 91-cm-diameter holes.

As a packer to retain the grout in horizontal holes and for sealing forming for grout pumped for blast-door frames, cable trenches, a steel bulkhead, instrument cable conduits, a concrete-block plug, and for a neutron gate grout collar, a quick-set cement "dry pack" was used. Fig. 5 shows "dry packing" performed to seal form for containing grout collar for neutron pipe gate.

4.3 SURFACE HOLES

To grout instrument and postshot recovery holes, one or two ready-mix concrete trucks were used. The grouting materials were batched and mixed

at the site as needed depending on the volume of grout required. In the case of holes requiring smaller volumes of grout, the 0.227-cu-m-capacity grout mixer was employed. The Gardner-Denver duplex pump was used to perform all the grouting for both the instrument and recovery holes, which were all vertical holes drilled from the surface. Injection hoses 2.540 cm in inside diameter were used to perform this grouting. The hoses were withdrawn from the recovery holes as the grout injection progressed; in the case of the instrument holes, the hoses were left in place following simultaneous introduction with the instrument string into the holes. Loss circulation left uncorrected by the drilling contractor was encountered in LRL 3 during instrument grouting. This condition was corrected by WES by stage grouting and introducing intermittent sand plugs as the grouting progressed.

4.4 PHYSICAL TESTS OF FIELD GROUT SPECIMENS

The following physical properties of specimens cast at the jobsite from mixtures 1 through 8 were determined on the device-detonation date. No data could be obtained for mixture 9 because insufficient grout remained after grouting was completed to cast specimens.

Mixture	Compressive Strength kg/sq cm	Ultrasonic Pulse Velocity m/sec	Unit Weight (Hardened) kg/cu m
1	345.7	3643	2119.4
2	409.3	--	----
3	90.3	--	----
4	143.3	3003	1872.7
5	280.3	--	----
6	184.8	2744*	1794.2*
7	287.4	--	----
8	477.1	--	----

* Approximate value; faulty specimens unsuitable for testing.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

5.1 DRILLING

As a result of the drilling techniques and equipment developed by WES for Project COWBOY, only minor difficulties which were considered normal were encountered during the drilling operations for Project GNOME.

5.2 GROUTING

In spite of all-but-inaccessible areas, crowded working conditions, need for haste, and general hindering activity, it is believed that all the varied grouting performed from the surface and within the tunnel met specifications. A greater variety of grout mixtures was pumped for Project GNOME than heretofore for other similar projects.

Tables 1, 2, and 3 give information on tunnel and surface holes, and tunnel structural appurtenances. Also listed in these tables are the mixtures used to perform the grouting for these items.

Table 1

Tunnel Holes

User	Hole No.	Length, m	Diameter, cm	Mixture No.
LRL	1	24.38	91.4	2
LRL	2	9.14	91.4	2
LRL	3	31.09	7.6	6
LRL	4	31.09	19.4	4
LRL	5	8.53	30.5	1
LRL	6	11.58	15.2	9* and 1
LRL	7	11.28	15.2	9* and 1
LRL	8	28.65	19.4	6
LRL	9	32.92	19.4	1
LRL	10	33.53	19.4	1
LRL	11	33.53	19.4	1
Sandia	12	41.15	19.4	1
Sandia	13	38.10	19.4	1
Sandia	14	41.15	19.4	1
Sandia	15	40.54	19.4	1
Sandia	16	40.23	19.4	1
Sandia	17	39.93	19.4	1
Sandia	18	39.93	19.4	1
Sandia	19	17.98	7.6	1
Sandia	20	3.05	7.6	1
Sandia	21	3.66	7.6	1
Sandia	22	3.66	7.6	1
Sandia	23	24.99	7.6	1
Sandia	24	20.42	7.6	1
LRL	25	21.64	12.7	1

* Instrument embedded with mixture 9; remainder of hole stemmed with mixture 1.

Table 2

Surface Holes

User	Hole No.	Length, m	Diameter, cm	Mixture No.
LRL	SR-2	359.66	30.5	3
LRL	SR-3	228.60	14.3	3
LRL	LRL-1	365.76	30.5	7*
SC	SC-2	320.04	30.5	1
SC	SC-3	365.76	20.3	1
SRI	SRI-1	365.76	12.7	6
SRI	SRI-2	365.76	12.7	6
SRI	SRI-3	365.76	12.7	6
SRI	SRI-4	365.76	12.7	6

* This hole was stemmed above the plug with graded Ottawa sand by WES to within approximately 121.9 m of the surface.

Table 3

Grouting, Structural Appurtenances, Tunnel

Appurtenances	Mixture No.	Remarks
Vertical cable trenches	8	Trenches extended from entrances of instrument holes down tunnel wall faces to tunnel floor. Sandia horizontal holes
LRL-1 hole key-plug	7	In roof of alcove located in immediate vicinity of sta 1+00
Blast-door frame	5	Main blast door, sta 9+00
Concrete-block plug	5	Approximate location between sta 8+00 and 9+00. Mixture used for bonding blocks to tunnel walls
Steel bulkhead for concrete-block plug	5	Steel beam bulkhead located at sta 9+00
Grout collar, neutron pipe gate	2	Approximate location sta 8+45
Cable conduits	5	Conduits through main blast door approximate location sta 9+50
Blast-door frame for personnel access tunnel	5	Adjacent to line-of-sight hole 2
7.62-cm-diameter cable hole for neutron pipe gate	5	Location vicinity sta 8+47

APPENDIX A

PHYSICAL PROPERTIES OF CORE SPECIMENS

A.1 PURPOSE

Tests on salt cores were conducted to provide information on the physical characteristics of the salt formation in the Project GNOME area for the various agencies participating in the project.

A.2 SCOPE

Eleven 5.4-cm- and four 11.4-cm-diameter cores obtained from the AEC exploratory hole 1 and from recovery hole 1 were brought to the WES laboratory and tested as described in the following paragraph.

A.3 TESTS PERFORMED

The following tests were performed on the eleven 5.4-cm and on three of the 11.4-cm cores obtained from the project site using principally test methods given in the Handbook for Concrete and Cement.*

a. Density; test method CRD-C 23.

b. Ultrasonic pulse velocity, determined by the time of transmission of pulse wave through length of specimen; test method CRD-C 51 (soniscope)

c. Dynamic modulus of elasticity, calculated from weight of specimen and longitudinal frequency; method CRD-C 18.

d. Dynamic modulus of elasticity, calculated from weight of specimen and transverse frequency; method CRD-C 18.

e. Sonic velocity, calculated from transverse frequency (method CRD-C 18) and length of specimen.

f. Poisson's ratio, Jones's method, calculated from b and c above.

Specimens were tested in "as received" condition and/or were inundated for 48 ± 4 hr and tested in saturated, surface-dry condition. Results of the tests are presented in table A1. The cores were identified as follows:

---

* Published by the Waterways Experiment Station in August 1949.

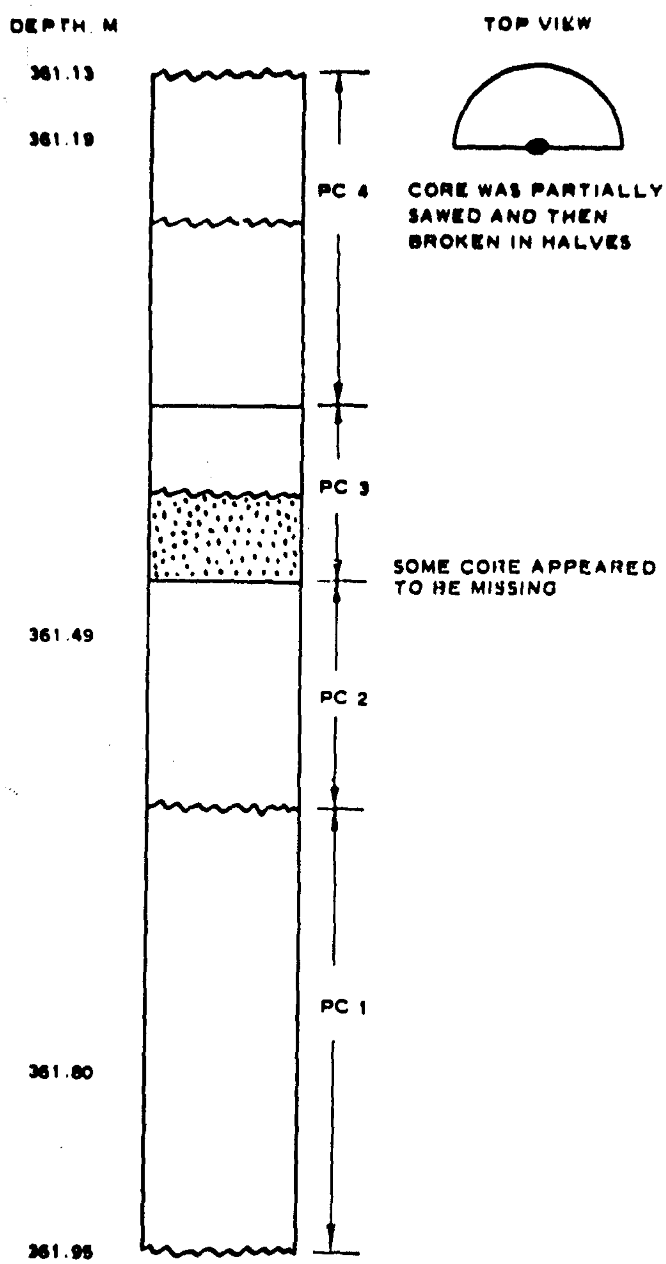
Serial No.	Description	Hole Depth, m
NMTS-1 G-1	5.4-cm salt core	398.7-399.0
NMTS-1 G-2(A)	5.4-cm siltstone core	63.7- 64.0
NMTS-1 G-2(B)	5.4-cm siltstone core	53.6- 53.9
NMTS-1 G-2(C)	5.4-cm siltstone core	62.8- 63.1
NMTS-1 G-2(D)	5.4-cm siltstone core	64.0- 64.3
NMTS-1 G-3	5.4-cm claystone core	172.2-172.5
NMTS-1 G-4(A)	5.4-cm anhydrite-salt core	98.1- 98.6
NMTS-1 G-4(B)	5.4-cm anhydrite-salt core	127.7-128.0
NMTS-1 G-4(C)	5.4-cm anhydrite-salt core	136.2-136.6
NMTS-1 G-5(A)*	5.4-cm polyhalite core	U. S. Potash Co., hole depth unknown
NMTS-1 G-5(B)*	5.4-cm polyhalite core	U. S. Potash Co., hole depth unknown
RH No. 1(1)	11.4-cm salt core	See fig. A1
RH No. 1(2)	11.4-cm salt core	See fig. A1
RH No. 1(3)**	11.4-cm polyhalite core	See fig. A1
RH No. 1(4)	11.4-cm salt core	See fig. A1

* Polyhalite NX core was unobtainable from AEC exploratory hole 1. Two cores considered representative of area polyhalite were obtained from U. S. Potash Co., Carlsbad, New Mexico.

** Only petrographic examination was conducted on this core.

A.4 PETROGRAPHIC EXAMINATION

In addition to the physical tests, a petrographic examination was performed on the four core specimens obtained from recovery hole 1. The results of this examination are given in fig. A1.

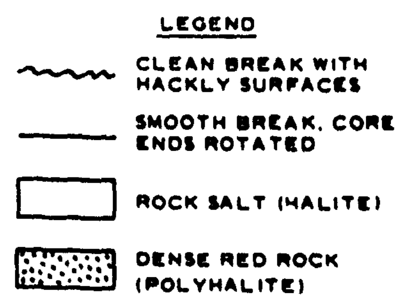


COMPOSITION. DENSE REDDISH ROCK SALT (HALITE) COLORED BY BITS OF POLYHALITE ROCK DISSEMINATED THROUGH THE CORE. THERE IS 5.08- TO 7.62-CM-THICK BED OF RED POLYHALITE IN PIECE 3. ITS COLOR IS DUE TO FINELY DIVIDED IRON OXIDE.

TEXTURE. ANHEDRAL SALT GRAINS UP TO 2.540 CM IN MAXIMUM DIMENSION. MOST GRAINS ARE 0.635 TO 1.270 CM. THE POLYHALITE IS DENSE AND VERY FINE GRAINED.

STRUCTURE. HORIZONTAL BEDDING IS INDICATED BY THE HALITE-POLYHALITE CONTACT.

REMARKS. POLYHALITE $(K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O)$ IS COMMONLY ASSOCIATED WITH ROCK SALT IN THE NEW MEXICO AREA. THE MINERAL HAS A HARDNESS OF 3-1/2 AND A SPECIFIC GRAVITY OF 2.78. IT DECOMPOSES IN WATER AND GYPSUM IS FORMED.



NOTE: 80.01-CM LENGTH OF 10.80-CM-DIAMETER CORE CUT DOWN THE CENTER.

Fig. A1. Petrographic examination of recovery hole 1 cores

Table A1

Test Results on Cores--Project GNOME

Specimen No.*	Bulk Density kg/cu m As Rec'd	Bulk Density kg/cu m SSD**	Ultrasonic Pulse Velocity m/sec As Rec'd	Ultrasonic Pulse Velocity m/sec SSD	Dynamic Modulus, kg/sq cm: Longitudinal Frequency $E \times 10^{-6}$ As Rec'd	Longitudinal Frequency $E \times 10^{-6}$ SSD	Transverse Frequency $E \times 10^{-6}$ As Rec'd	Transverse Frequency $E \times 10^{-6}$ SSD	Sonic Velocity Using Long. Freq m/sec As Rec'd	Sonic Velocity Using Long. Freq m/sec SSD	Poisson's Ratio As Rec'd	Poisson's Ratio SSD
AEC Exploratory Hole 1												
NMTS-1 G-1	2145	--	--	--	---	---	---	---	--	--	--	---
NMTS-1 G-2(A)	2595	--	--	--	---	---	---	---	--	--	--	---
NMTS-1 G-2(B)	2325	2415	1620	--	0.038	---	0.076	---	1270	--	0.35	---
NMTS-1 G-2(C)	2445	2495	2185	2855	0.031	0.031	0.061	0.069	1105	1095	0.45	0.47
NMTS-1 G-2(D)	2425	2465	2310	2965	0.043	0.040	0.151	0.032	1330	1255	0.43	0.465
NMTS-1 G-3	2215	--	2080	--	0.073	---	0.079	---	1780	--	0.31	---
NMTS-1 G-4(A)	2325	2325	5385	4410	0.408	0.409	0.408	0.406	4120	4125	0.37	0.225
NMTS-1 G-4(B)	2335	2325	5475	4360	0.430	6.399	0.439	0.405	4005	4030	0.38	0.24
NMTS-1 G-4(C)	2315	2315	4285	4270	0.057	0.057	0.103	0.102	1525	1525	0.47	0.47
NMTS-1 G-5(A)	2620	2625	4210	--	---	---	---	---	--	--	--	---
NMTS-1 G-5(B)	2715	2685	4380	4765	0.064	0.063	---	0.062	1510	1500	0.47	---
Recovery Hole 1												
RH No. 1	--	--	3460 3940†	--	---	---	---	---	--	--	--	---
RH No. 2	2115	--	4030	--	---	---	---	---	--	--	--	---
RH No. 3††	--	--	--	--	---	---	---	---	--	--	--	---
RH No. 4	2145	--	4280 4185†	--	---	---	---	---	--	--	--	---

Note: Where no tests are indicated, specimens were for various reasons unsuitable for individual tests or agency requested only the test or tests indicated.

* The ends of all specimens were sawed for testing.

** Saturated, surface dry.

† Test result following sawing of specimen RH No. 1 and RH No. 4 from 22.70- and 14.29-cm lengths to 20.16- and 11.75-cm lengths, respectively.

†† This specimen used for petrographic examination only.

TECHNICAL REPORTS SCHEDULED FOR ISSUANCE BY AGENCIES PARTICIPATING IN PROJECT GNOME

AEC REPORTS

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LRL	PNE-101	Power Studies
LRL	102	Isotopes Program
ORNL	103	Design of Sequenced Gas Sampling Apparatus
LRL	104	Close-In Shock Studies
LRL	105	Stress Measurements with Piezoelectric Crystals
LRL	106	Post-Shot Temperature and Radiation Studies
LRL	107	Geologic Studies of the Tunnel and Shaft
SC	108	Particle Motion near a Nuclear Detonation in Halite
SRI	109	Earth Deformation from a Nuclear Detonation in Salt
USC&GS	110	Seismic Measurements from a Nuclear Detonation in Halite
SRI	111	Intermediate-Range Earth Motion Measurements
LRL	112	An Investigation of Possible Chemical Reactions and Phase Transitions Caused by a Nuclear Explosiv Shock Wave
LRL	113	Resonance Neutron Activation Measurements
LASL	114	Symmetry of Fission in U^{235} at Individual Resonance
EG&G	115	Timing and Firing
WES	116	Design, Test and Field Pumping of Grout Mixtures
USWB	126	Preliminary Report of Weather and Surface Radiation Prediction Activities for Project Gnome; Final Analysis of Weather and Radiation Data
H&N, INC	127	Pre-Shot and Post-Shot Structure Survey

GENCY	REPORT NO.	SUBJECT OR TITLE
FB, INC	PNE- 128	Summary of Predictions and Comparison with Observed Effects of Gnome on Public Safety
C	129	Monitoring Vibrations at the US Borax and Chemical Company Potash Refinery
JSGS	130	Hydrologic and Geologic Studies
FAA	131	Federal Aviation Agency Airspace Closure
JSPHS	132	Off-Site Radiological Safety Report
REE Co	133	On-Site Radiological Safety Report
USBM	134	Pre and Post-Shot Mine Examination

ABBREVIATIONS FOR TECHNICAL AGENCIES

ARA	Allied Research Associates Inc., Boston
EG&G	Edgerton, Germeshausen, and Grier, Inc., Boston, Las Vegas, and Santa Barbara
ERDL	USA C of E Engineer Research and Development Laboratories, Ft. Belvoir
GeoTech	The Geotechnical Corporation, Garland
LASL	Los Alamos Scientific Laboratories, Los Alamos
LRL	Lawrence Radiation Laboratory, Livermore
SC	Sandia Corporation, Albuquerque
SGC	Space-General Corporation, Glendale
SRI	Stanford Research Institute, Menlo Park
STL	Space Technology Laboratories, Inc., Redondo Beach
TI	Texas Instruments, Inc., Dallas
USC&GS	Coast and Geodetic Survey, Washington, D. C. and Las Vegas
USGS	Geological Survey, Denver
WES	USA C of E Waterways Experiment Station, Jackson
FAA	Federal Aviation Agency, Salt Lake City
H&N, Inc.	Holmes and Narver, Inc., Los Angeles
RFB, Inc.	R. F. Beers, Inc., Alexandria
REECo	Reynolds Electrical and Engineering Co., Las Vegas
USBM	U. S. Bureau of Mines, Washington, D. C.
USPHS	U. S. Public Health Service, Las Vegas
USWB	U. S. Weather Bureau, Las Vegas

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